■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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IEP QUARTERLY HIGHLIGHTS

October-December 2004

Acute Mortality and Injury of Delta Smelt Associated with Collection, Handling, Transport, and Release at the State Water Project and Central Valley Project Fish Salvage Facilities

Jerry Morinaka (DFG), jmorinaka@delta.dfg.ca.gov

The "Acute Mortality and Injury of Delta Smelt Associated with Collection, Handling, Transport, and Release at the State Water Project and Central Valley Project Fish Salvage Facilities" program is part of a comprehensive program designed to investigate the impacts of existing collection, handling, transport and release (CHTR) systems and the potential benefits of new CHTR technologies on salvaged delta smelt from the state and federal water project facilities. This program will specifically measure the acute mortality and injury rates of both cultured and wild delta smelt during relatively high entrainment periods. The program will also compare survival and injury rates of adult delta smelt tested in winter against the rates of juvenile delta smelt tested in spring.

The proposal for this program element is presently in the final development stage. Following internal review of the proposal in early 2003, the proposal was distributed for an outside review coordinated by the California Bay-Delta Authority Science Program. Comments from these reviewers were received in late November 2003. Written responses to the reviewers' comments were assembled by late December 2003 and have been sent to the IEP Management Team (MT) and the Central Valley Fish Facilities Review Team (CVFFRT) for review. The principal investigator will meet with the MT and CVFFRT in January 2004 to discuss the reviews and responses, and then will make any necessary revisions to the proposal before it is sent to the IEP Coordinators with MT and CVFFRT recommendations in early February 2004.

Assessment of Fish Predation Occurring in the Collection, Handling, Transport, and Release Phase of the State Water Project's John E. Skinner Delta Fish Protective Facility Fish Salvage Operation

Geir Aasen (DFG,) gaasen@delta.dfg.ca.gov

This proposed study investigates delta smelt (*Hypomesus transpacificus*) losses during the fish collection, handling, transport, and release (CHTR) phase of the fish screening and salvage process at the State Water Project's John E. Skinner Delta Fish Protective Facility (DFPF). This study will be done in 2004 in conjunction with the Acute Mortality and Injury Evaluation Study and the Diagnostic Indicators Evaluation Study.

Because no comprehensive predation loss studies have been attempted during the CHTR phase of salvage at the DFPF, we propose to examine predation losses for all species. Past studies and observations have shown that predation occurs in the secondary screening and holding tank phases (prior to the CHTR phase). Results from this proposed study will be used to determine if further predation studies focused on delta smelt are warranted.

Our objective is to determine the occurrence and magnitude of predation in the CHTR Phase. This study will compare stomach contents of potential predators before and after the CHTR phase of salvage during routine operations. Stomach contents of predators sampled at the end of the holding tank period (pre-CHTR samples) will be compared with those of predators collected, handled, transported for 45 minutes (to simulate drive time to a release site in the delta), and released into an above-ground pool with a rotary screen (post-CHTR samples). We hope to determine whether significant levels of predation occur before the CHTR phase or is negligible during the CHTR phase.

Our second approach will employ a more direct observational method to determine the extent of prey fish consumption during the CHTR phase. Specifically, we will use empirically developed digestion indices through controlled feeding trials to determine if prey fish observed in post-CHTR stomach samples were likely consumed during the CHTR Phase.

This proposal is currently undergoing review for implementation. A draft of the proposal was submitted for review to four anonymous scientists and comments were generally favorable. IEP Management Team and Central Valley Fish Facilities Review Team recommendations on the revised

proposal will be sent to the IEP Coordinators who will make a final decision about funding and implementation of this study.

Development of Diagnostic Indicators to Predict Acute or Chronic Adverse Effects to Salvaged Delta Smelt

Virginia Afentoulis (DFG), vafentoulis@delta.dfg.ca.gov

This study is being proposed to investigate methods of stress assessment on delta smelt (*Hypomesus transpacificus*) subjected to the collection, handling, transport, and release (CHTR) phases of the salvage process at the Skinner Delta Fish Protective Facility (DFPF).

Stress is a concern for anyone who handles live fish because stress can cause reductions in growth, reduced performance, reproductive impairment, and sometimes death in fish. Because stress is a concern and because little is now known about the effect of CHTR processes on delta smelt, I have selected the following types of stress assessment techniques for investigation: plasma cortisol, blood glucose and lactate, swim performance, and reproductive success assays. It is expected that these methods will show a stress impact to delta smelt. In addition, this work may give an idea of the ecological significance of facility-induced stress on this species given that each measures stress effects at consecutively higher levels of organization.

Blood plasma cortisol collection experiments will measure cortisol levels in groups of 20 fish at different time intervals post CHTR to assess acute stress and recovery within 48 hours of exposure (blood glucose and lactate will also be measured). Swim performance will be tested on individual fish in a Brett-type swim chamber immediately following CHTR exposure; this will give an indication of whether any acute stress has a lasting effect on the critical swimming velocity between control fish and CHTR-exposed fish. I have also proposed an experiment to compare CHTR-exposed delta smelt with control fish to indicate if there is any reproductive disruption due to stress. Possible stress-related disruptions are spawning delay or no spawn, and reductions in amount of eggs or offspring produced.

This study proposal is currently undergoing review by the IEP and Calfed. An original draft was submitted in June 2003 for review by an independent panel of scientists and comments were just received in November 2003. Responses to the reviewer's comments were submitted by the proposal author to the IEP Coordinators and Central Valley Fish Facilities Review Team on December 23, 2003. The final decision for approval of the proposal for funding and implementation will be on February 5, 2004.

Effects of Covering Secondary Screen/Louvers at the Skinner Fish Facility

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The primary purpose of the "Effects of Covering Secondary Screen/Louvers at the Skinner Fish Facility" program element is to determine the effect darkening the secondary screen bays during the daylight hours has on salvage rates of Delta fish. The study implementation phase of the program element was initiated in summer 2002 and continued through summer 2003. The majority of test trials have been conducted during the summer months due to factors involving facility operations and fish salvage. During several months of the year the facility is shut down during the daylight hours and operated primarily at night. Also, during some of the winter months, insufficient numbers of fish are salvaged to run useful trials. The data from the past two years are currently being analyzed. If the opportunity arises, additional trials may be conducted in 2004, concentrating on periods when the Skinner Fish Facility is salvaging listed fish species.

2003 Suisun Marsh Salinity Control Gates Adult Salmon Telemetry Study

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The adult salmon telemetry study at the Suisun Marsh Salinity Control Gates (SMSCG) in Montezuma Slough was successfully completed November 10, 2003. A total of 163 adult fall-run Chinook salmon were implanted with ultrasonic transmitters (tagged), released downstream from the salinity control gates, and monitored for passage time and passage rate over a 6-week period that encompassed three operational configurations (phases) of the gates:

Phase	Date	Gates	Flashboards	Boat Lock
I	Sept. 30 – Oct. 13	Tidally operated	Installed	Operated
II	Oct. 14 – 27	Tidally operated	Installed	Held open
III	Oct. 28 – Nov. 10	Held open	Removed	Operated

During Phase I, 54 adult salmon were tagged, with 29 passing through the gates (54%), 23 not passing (42%), and 2 with no records (4%). The mean passage time for Phase I was 38.9 hours. During Phase II, 43 adult salmon were tagged, with 28 passing through the gates (63%), 13 not passing (30%) and 3 with no records (7%). The mean passage time for Phase II was 52.5 hours. Phase III had 65 salmon tagged, with 46 passing through the gates (71%), 16 not passing (25%) and 3 with no records (4%). The mean passage time for Phase III was 36.4 hours.

The SMSCG study focused on the use of the boat lock as an alternate means of fish passage when the gates where operating normally. Preliminary findings show a slightly higher rate of passage when the open boat lock was available for migrating adult salmon (Phase II). However, the mean time of passage was longer compared to the operational phase with the boat lock closed (Phase I) and when the gates were held open (Phase III).

The 2003 SMSCG study used the boat lock as alternate passage for the third year. The results from the 2001 and 2003 studies are similar, with the highest rate of passage occurring during the phase when the boat lock was open. The results from the 2002 study, however, showed that the boat lock open phase had the lowest rate of passage for all years of the study. Further analysis and comparison of all three years, and a possible fourth year of the study in 2004, may help to validate the effectiveness of using the boat lock as a permanent means to facilitate fish passage in Montezuma Slough.

Adult Salmon Telemetry: Relating Movements to Flow at Specific Junctions of the Delta

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We deployed 29 Vemco VR2 monitoring stations at locations in the north Delta, interior Delta, Three-Mile Slough, and San Joaquin River at Mossdale to detect 163 ultrasonically tagged adult Chinook salmon from Montezuma Slough. These salmon were tagged by the Suisun Marsh Group (DFG and DWR) from September 30 to October 31, 2003, on a concurrent study to determine the effects the salinity control gates have on fish passage. We further monitored salmon movements as they exited Montezuma Slough and moved through the Delta. VR2 monitors logged tag detections from October 1; the monitors will be removed from the Delta as of January 1, 2004. Our collaborators, the United States Geological Survey, will provide flow measurements in the interior Delta, north Delta, and Three-Mile Slough using SL UVM and XR Argonaut monitors.

The information obtained from salmon detections will allow us to describe their directional movements, transit times, swimming speeds, and preferred migratory pathways. We will integrate flow measurements with fish movement at specific junctions of the Delta to identify patterns of movement and correlate fish movement to flow.

We will report the preliminary results after all VR2 monitoring stations and Argonaut flow stations have been recovered, and the movement and flow data have been analyzed. We will develop a series of animations to depict the movement of salmon through Delta waterways and the accompanying flow vectors.

Dayflow Program Update

Brad Tom, Kate Le, and Chris Enright (DWR), cenright@water.ca.gov

Introduction

The Dayflow program has been updated. Historical and current Dayflow output has been adjusted by modifying the computational scheme to take advantage of new data sources. The Dayflow website includes complete updated

documentation of the computational scheme. Previous Dayflow documentation is also available at the site.

All Dayflow users are encouraged to replace their current output files with the updated files now available online at http://www.iep.ca.gov/dayflow/. Additional modification details are also available on the site.

Specific adjustments to the parameters, associated effects, and website updates are described below.

Computational Scheme Updates

1. The definition of QSWP has been changed to improve the representation of the State Water Project's (SWP) direct influence on Delta currents, water levels, and transport of biota. The parameter QSWP previously was assigned the value of pumping at Banks Pumping Plant. The definition of QSWP was changed to Clifton Court Forebay (CCF) Inflow (or pumping at Banks Pumping before April 20, 1971). Values of the following parameters changed as a result of the changes in QSWP: QEXPORTS, QWEST, QOUT, EXPIN, QDIVER, and QEFFDIV. Tables 1-6 summarize these changes. There are significant differences in some the daily values when the SWP pumped water from the CCF when the gates were closed. Average daily differences for each water year are small.

Table 1 Changes in QSWP due to definition change

Water year	*Max. daily difference (cfs)*	*Avg. daily difference (cfs)*
1970-1983	3816	49
1984-1996	3616	44
1997	2770	47
1998	4694	26
1999	1908	38
2000	3609	27
2001	2190	43
2002	1940	37

Table 2 Changes in QEXPORTS due to changes in QSWP

Water year	*Max. daily difference (cfs)*	*Avg. daily difference (cfs)*
1970-1983	3816	49
1984-1996	3616	44
1997	2770	47
1998	4694	26
1999	1907	39
2000	3609	27
2001	2190	43
2002	1940	37

Table 3 Changes in QWEST due to changes in QSWP and QXGEO

Water year	*Max. daily difference (cfs)*	*Avg. daily difference (cfs)*
1970-1983	3816	-49
1984-1996	3616	-44
1997	2769	-47
1998	4694	-26
1999	1907	-39
2000	3609	-27
2001	2190	-44
2002	1939	-37

Table 4 Changes in QOUT due to changes in QSWP

Water year	*Max. daily difference (cfs)*	*Avg. daily difference (cfs)*
1970-1983	3816	-49
1984-1996	3616	-44
1997	2771	-47
1998	4694	-26
1999	1907	-39
2000	3609	-28
2001	2189	-44
2002	1941	-37

Table 5 Changes in QDIVER due to changes in QSWP

Water year	*Max. daily difference (cfs)*	*Avg. daily difference (cfs)*
1970-1983	30	0.29
1984-1996	34	0.27
1997	11	0.21
1998	7	0.08
1999	9	0.16
2000	11	0.15
2001	14	0.25
2002	11	0.22

Table 6 Changes in QEFFDIV due to changes in QSWP

Water year	*Max. daily difference (cfs)*	*Avg. daily difference (cfs)*
1970-1983	32	0.32
1984-1996	40	0.31
1997	13	0.19
1998	9	0.11
1999	10	0.18
2000	13	0.12
2001	15	0.25
2002	12	0.16

2. The parameter QXGEO was previously estimated as the sum of Delta Cross-Channel and Georgiana Slough flows. Empirical equations were developed in 1978 using historical data to relate these flows to Sacramento River flow (QSAC) at I Street Bridge in Sacramento. In 2002, the US Geological Survey (USGS) began collecting flow data in Georgiana Slough and the Delta Cross-Channel. Starting with water year 2003, the definition of QXGEO was changed to the sum of these two flows. There are a number of missing values in the observed Delta Cross-Channel data set from March-September 2003. The empirical equations were used to calculate QXGEO whenever observed data were not available. Figure 1 compares QXGEO calculated as the sum of observed data to QXGEO calculated using the empirical equations for water year 2003. For more information, see the Dayflow documentation.

3. The Dayflow program was updated to correct an error in the way QXGEO has been calculated. Values changed slightly for water years 1997-2002. Values of QWEST and QRIO changed by the same amount. Table 3 lists the changes in QWEST due to changes in QSWP and QXGEO. Table 7 lists the changes in QXGEO and the resulting changes in QWEST and QRIO.

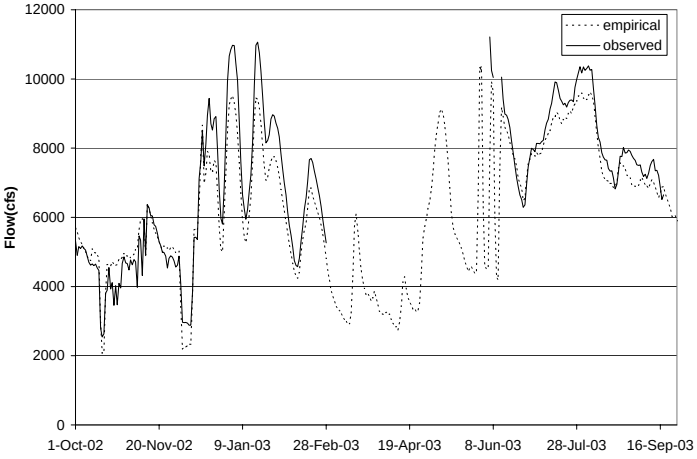

Figure 1 WY 2003 QXGEO observed data vs. empirical equation results

Table 7 QXGEO, QWEST, and QRIO changes due to Dayflow program correction

Water year	*Min. difference*	*Max. difference*	*Avg. difference*	*Min. % difference*	*Max. % difference*	*Avg. % difference*
1997	-187	188	-0.04	-4.14	3.98	-0.01
1998	-242	-213	-0.52	-4.37	2.9	-0.01
1999	0	171	0.47	0	2.8	0.01
2000	-166	171	-0.34	-3.87	2.94	-0.02
2001	-214	142	-0.03	-4.59	3.45	0
2002	-279	184	-0.16	-3.72	3.43	-0.01

Update on Chinese Mitten Crab Public Reporting System

David Bergendorf and Erin Williams (USFWS), david_bergendorf@fws.gov

In 2001 the Stockton Fish and Wildlife Service Office, in conjunction with the California Department of Fish and Game, set up a reporting system for Chinese mitten crabs (*Eriocheir sinensis*). The reporting system consists of a toll free number 1 (888) 321-8913, paid-postage surveys, and an online reporting form at http://www.delta.dfg.ca.gov/mittencrab/sightings.asp.

The number of reported mitten crab sightings throughout the San Francisco Bay and the Sacramento-San Joaquin River Delta has decreased since the program began in 2001. Public reports of mitten crabs to the reporting system have declined from 147 in 2001 to 53 in 2002 and to 22 in 2003. Other types of monitoring suggest that the population has been declining since 1998. Adult mitten crab counts at the State Water Project (SWP) and John Skinner Fish Protective Facility (SWP) and the Central Valley Project (CVP) and Tracy Fish Collection Facility (CVP) have declined from a maximum in 1998 to a minimum in 2003 (Table 1).

The number of mitten crabs could quickly rebound as has been seen with other populations of introduced mitten crabs. Age 0+ mitten crabs appear to be most abundant in stretches of streams near the San Francisco Bay (see "Assessment of Mitten Crab Habitat Preference and Monitoring Methods in the San Francisco Estuary" in this issue).

Table 1 Annual adult mitten crab count at the Skinner Fish Protective Facility (SWP) and the Central Valley Project and Tracy Fish Collection Facility (data provided by Steve Foss, DFG)

Year	SWP	CVP
1998	272,704	N/A
1999	25,192	39,582
2000	4,702	2,556
2001	7,293	27,282
2002	1,178	2,450
2003	90	648

News from Around the Estuary

Program Implemented to Prevent the Establishment of the Invasive Zebra Mussel in California[1]

Tanya Veldhuizen and Cindy Messer (DWR), mussel@water.ca.gov

The zebra mussel, *Dreissena polymorpha*, is a small, freshwater mussel whose shell usually has alternating light and dark brown stripes, but can also be solid light brown or dark brown (Figures 1 and 2). Like the mussels found clinging to the rocks along the California coastline, zebra mussels attach onto hard surfaces (for example, pipes, screens, rock, logs, boats, etc.). No other freshwater mussel or clam in California can attach onto a hard surface. Zebra mussels form colonies made up of many individuals attached to a single object.

Figure 1 Zebra mussels are usually less than 2 inches long. Photo by USGS.

1. This article was published in *Pisces* (Vol. 32, No. 4, Winter 2003-04).

Figure 1 Figure 2 The zebra mussel has several color morphs—light brown, dark brown, and striped. Photo by USGS.

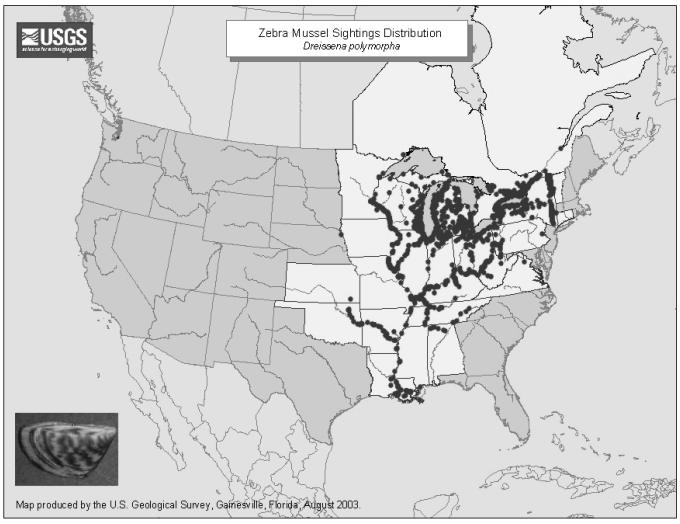

Figure 3 Distribution of the zebra mussel in the United States and Canada, August 2003. Map by USGS.

Zebra mussels are native to the Caspian Sea and Aral Sea region near Russia and the Ukraine. They were first discovered in North America in Lake St. Clair, a small water body connecting Lake Huron and Lake Erie, in June 1988. Within months of the discovery, large numbers of zebra mussels began to appear in Lake St. Clair and along the northern shoreline of western Lake Erie. The distribution of zebra mussels now covers most of the midwestern United States and is expanding into eastern states (Figure 3).

Initial introductions were most likely from foreign ballast water releases. Dispersal has mostly been due to the mussel's ability to attach to boats and barges that are then either navigated or trailered to other waterbodies. Under cool and humid conditions, zebra mussels can survive out of water for several days. At California border crossings, inspectors have discovered several live and dead zebra mussels attached to boat hulls or in boat engine compartments (Figure 4).

Figure 4 Inspectors at the agricultural inspection station in Truckee, CA, found zebra mussels attached between the hull and trim tabs of this boat. Instead of cleaning the boat before launching as instructed, the commercial hauler abandoned the boat in a marina parking lot in Stockton, CA. The parking lot flooded that winter, potentially inoculating the Sacramento-San Joaquin Delta with zebra mussels. Photo by K Webb, USFWS.

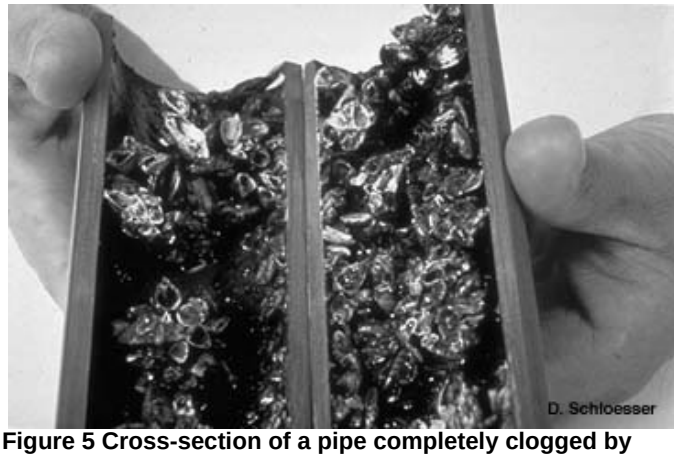

Figure 5 Cross-section of a pipe completely clogged by zebra mussels. Photo by D Schloesser, Great Lakes Science Center.

Because zebra mussels form dense colonies on hard substrates, they can reduce the pumping capacity of water intake pipes and encrust submerged mechanical equipment. This has resulted in millions of dollars in damage to water intake structures and delivery systems, such as those used for power and municipal water treatment plants, in the midwestern and eastern United States from the Great Lakes into the Mississippi drainage (Figure 5). Based on this information, water and power facilities in California have a high potential of being adversely affected by zebra mussels. Impacts to fish screens and hatcheries are also of concern.

Zebra mussels also affect vessel owners. The mussels can attach to hulls and outboard motors, clog engine cooling systems, and impair steering mechanisms, resulting in increased fuel consumption and maintenance costs. Also, vessels can no longer be stored for long periods in the water.

Ecological impacts associated with the invasion of zebra mussels would probably be similar to those seen after the introduction of the Asian clam, *Potamocorbula amurensis*, in 1986, albeit more in the freshwater regions of the San Francisco Bay-Delta system and watershed. Like the Asian clam, zebra mussels are filter feeders and remove planktonic organisms, which are essentially the basis of the aquatic food web. Studies have shown that zebra mussels have increased water clarity in Lake Erie up to six times what it was prior to their arrival. The increase in water clarity has resulted in an increase in the growth and expanse of aquatic plants, many of which are also unwanted introduced pests. The alteration of the aquatic food web and aquatic habitats in the Sacramento-San Joaquin Delta and upstream environment through the establishment of the zebra mussel could negatively affect key fish species, such as Chinook salmon, delta smelt, splittail, and striped bass.

In response to this threat, the California Department of Water Resources (DWR), with funding from the California Bay-Delta Authority (CBDA[1]), implemented a comprehensive program to protect our watershed and water supply from the invasive zebra mussel. The "Zebra Mussel Detection and Outreach Program" is a multi-year project that began in 2001. The project entails a public outreach and education program, a risk assessment for California, an early detection monitoring program, and a rapid response plan. For outreach purposes, this project is referred to as the "Zebra Mussel Watch" program.

The objectives of the public outreach and education program are to provide information on how to identify zebra mussels, how to prevent their introduction (for example, how to properly clean boats), and what to do if zebra mussels are found in California. This program focuses on several specific counties (Sacramento, San Joaquin, Butte, Fresno, Merced, Glen, Colusa and Tehama), but brochures and other information are circulated throughout California.

The risk assessment involves determining which waterbodies in California have a high risk of zebra mussel establishment. High risk areas have suitable zebra mussel habitat (for example, substrate, pH, and mineral availability), appropriate water temperatures for spawning, adequate food supplies, and high levels of boating activity.

Early detection monitoring is conducted at high risk areas in the Bay-Delta system, as well as rivers and reservoirs in Sacramento, San Joaquin, Butte, Fresno, Merced, Glenn, Colusa, and Tehama counties. Sampling primarily consists of suspending an artificial substrate for zebra mussels, then checking this substrate monthly for the presence of zebra mussels. The artificial substrate consists of a Plexiglas plate and 2 PVC pipes filled with fabric mesh. These components are attached to a line of rope that is weighted at one end and can be suspended from a variety of structures located in the waterbody, including boat docks and slips, pipes, and piers. The artificial substrate monitoring is conducted by private citizens, marina staff, DWR staff, and staff from other agencies. During peak spawning months, DWR staff will sample for planktonic zebra mussel larvae. This more active form of sampling will only occur in areas deemed to be exceptionally high risk sites.

A centralized system is being established for reporting zebra mussel sightings. This system consists of a toll-free "zebra mussel hotline" and a website. Key information about zebra mussel sightings will be distributed via e-mail, the Internet, and phone calls to all necessary agencies, organizations, and facilities. A list of appropriate personnel from these agencies, organizations and facilities is currently being compiled and will be updated frequently as new parties express interest in being notified.

A rapid response plan is being developed to provide guidelines for zebra mussel sighting confirmation and appropriate eradication measures. This plan will provide a list of regulatory agencies to contact in the event of zebra mussel detection, identify the regulatory approvals necessary, identify the funds necessary for eradication of zebra mussels in California, and propose control and eradication strategies.

1. Formerly known as CALFED.

Protect your Watershed from Zebra Mussels: Become a Volunteer Monitor

Cindy Messer and Tanya Veldhuizen (DWR), mussel@water.ca.gov

It is very likely zebra mussels will someday become established in California waterbodies. Overland transport of recreational watercraft is the primary vector of zebra mussels. When the agricultural inspection stations began inspecting boats on trailers entering California in October 1993, inspectors found zebra mussels on a boat within six weeks. Zebra mussels were found on 24 boats between 1993

and April 2000. We feel this is a very high number considering that the inspections are not mandatory and the inspection stations are not open at all times. To make matters worse, currently 6 out of the 11 stations are closed because of California's budget crisis. The operating hours of the remaining 5 stations have been severely reduced and boat inspections are no longer being conducted. With this line of defense gone, we need to increase our public awareness efforts and become vigilant about monitoring for zebra mussels.

Why Monitor for Zebra Mussels?

Early Detection

The objective of field monitoring is to detect zebra mussels during the initial stage of establishment. To eradicate zebra mussels from a water body, we must implement control measures when the population is small and isolated. Early detection is the key to successful eradication. A rapid response plan will be in place and will contain guidelines and instructions for responding to a zebra mussel invasion.

Prevent Spread

Our ability to successfully eradicate or control an infestation of zebra mussels is more feasible and less costly if the population is isolated to a single lake as opposed to widespread in a watershed. Therefore, containing new zebra mussel populations is extremely important. In the event zebra mussels are discovered in a lake, the California Department of Fish and Game (DFG), along with other state and federal agencies, will take steps to prevent the mussel from spreading to other lakes and rivers. These steps may include boat cleaning at the infested lake, increasing public education and awareness efforts, and modifying the use of the infested lake.

Time to Prepare

Early detection gives water facility managers some time to retrofit their facility to ensure uninterrupted water deliveries. Facility managers will need to change operating procedures to adapt to and minimize the impacts of zebra mussels. Such measures may include: retrofitting intake valves with customized filters designed to screen out mussels; painting irritant coatings on surfaces to prevent mussels from settling; periodically flushing the system with high concentrations of chemicals (such as chlorine) or hot water to kill attached mussels; or periodically pressure washing all surfaces with hot water to kill and remove attached mussels. All of these measures are very costly and may require temporary facility shutdowns.

What You Can Do to Help

- Volunteer to monitor your lake, reservoir, or river. The time commitment is minimal (about 30 minutes per month), and the Zebra Mussel Watch program supplies the equipment.
- Inform others about how to prevent the spread of zebra mussels.
- Look for zebra mussels in your lake or reservoir by inspecting objects left in the water for long periods of time (for example, boats, logs, aquatic vegetation, buoys, and boat docks and ramps).
- Inspect out-of-state boats and trailers for zebra mussels.
- Clean and inspect your boat regularly and teach others to do the same.

How to Report Sightings

If you find zebra mussels, collect several specimens and record the precise location (for example, water body, nearest landmark, GPS coordinates, etc.), date, and contact information. Preserve the specimens in ethanol, in rubbing alcohol, by freezing them, or by allowing them to air dry. Immediately notify Zebra Mussel Watch staff by phone (1-888-840-8917) or e-mail (mussel@water.ca.gov) for further instructions.

To Learn More

More information about zebra mussels and other introduced aquatic animals and plants can be found at the following websites:

http://www.100thmeridian.org (The 100th Meridian Initiative)
http://www.nsgo.seagrant.org (National Sea Grant Program)

or by contacting:
Zebra Mussel Watch Program
Phone: 1 (888) 840-8917 (toll free)
Fax: (916) 227-7554
E-mail: mussel@water.ca.gov

Fisheries Research Website Now Available for Tracy Fish Collection Facility

Peter Soeth (USBR), psoeth@do.usbr.gov

The US Bureau of Reclamation has developed a new research Web site for the Tracy Fish Collection Facility. This website describes research being performed for the Central Valley Project Improvement Act and has broad applications for fishery protection at large water diversions in the South Delta region of California. The website provides the public and cooperating agencies access to unique research data specifically devoted to the development of fish protection techniques and the latest technology used in fish research.

Besides providing general information, the website provides links to collaborating agencies, peer-reviewed technical reports, and photos of program activities at the Tracy facility, the Denver Research Laboratories, and the Red Bluff Research Pumping Plant. Summary reports from all facilities can be viewed and downloaded as Adobe Acrobat PDF files. Water quality data, collected every 30 minutes from a probe installed in the intake channel of the Tracy Facility, is also available for download.

The website address is: http://www.usbr.gov/pmts/tech_services/tracy_research/

For questions, please contact Doug Craft, Research Chemist, USBR's Denver Office, (303) 445-2182 or e-mail: DCRAFT@do.usbr.gov.

CONTRIBUTED PAPERS

Zooplankton Abundance Patterns in Grizzly Bay

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Do shallow-water habitats in estuaries function as important nurseries for young estuarine fishes? In spite of considerable research on this topic (for example, Kneib 1997), this question remains open for the San Francisco Estuary (Brown 2003). In particular, not much is known about the characteristics of the extensive shoals in the various embayments of the estuary. Most monitoring for fish in the estuary, including the Suisun Marsh study, has been concentrated largely in channels or in water at least 3 meters deep (Moyle and others 1986, Kimmerer and others 2001, Matern and others 2002). Zooplankton monitoring likewise has been conducted mainly at stations in channels (including Suisun Marsh) and deeper parts of shoal areas (Orsi and Mecum 1986).

While shallow-water habitat (SWH) may provide benefits to young fish, these benefits may not be due to higher concentrations of food. Zooplankton appear to be less abundant in shallow areas compared to channels in Suisun Bay (Kimmerer and others 1998). Research here and in other geographic areas suggests that this may be due to the behavior of some zooplankton (Ambler and others 1985, Kimmerer and others 1998) or consumption by planktivorous fishes that congregate in shallow-water areas (Kimmerer and McKinnon 1989, Kimmerer 1991). Thus, shallow habitat should not be viewed as a static location that is good or bad for young fish, but as a dynamic place where predator-prey interactions may have important effects on densities, population sizes, and individual growth rates of fishes and zooplankton.

Much of the recent interest in SWH has been generated by the use of X_2 (an estimate of the location of the Low-Salinity Zone) as a regulatory/management tool and disagreements over the validity of the tool, indicating different perceptions of the concepts underlying it. SWH appears important because of the observation that survival or abun-

dance of some low-salinity organisms is enhanced through one or more mechanisms when the Low-Salinity Zone is positioned adjacent to SWH, such as Honker Bay and Grizzly Bay.

The recent Entrapment Zone studies have provided important insights into the hydrodynamics of the Low-Salinity Zone (previously known as the entrapment zone) and the mechanisms by which some zooplankton and larval fish maintain position in that habitat (Kimmerer and others 1998, 2002; Schoellhamer 2001; Bennett and others 2002). Although these studies focused on the deeper channels of Suisun Bay, much speculation arose on the importance of the interaction between shoal and channel habitats for enhancing retention and survival of organisms associated with the Low-Salinity Zone. Drifter studies in Honker Bay and Grizzly Bay suggest that water retention time in such areas is on the order of days or less (Lacy 1999, Jon Burau, unpublished data) compared to the generation times of zooplankton (weeks), suggesting that active retention mechanisms would be required for retention.

Deployment of hydrodynamic instruments in the vicinity of Grizzly Bay during 1999-2000 provided a unique opportunity to evaluate the significance of SWH to zooplankton and young fishes. A research program was conducted to answer the following questions: (1) Do zooplankton and larval/juvenile fishes maintain abundance in the SWH (i.e., shoal-edge habitat) in Grizzly Bay? (2) Do zooplankton and larval fish behave in a way that maintains position on the shoals? (3) How significant is the transport of organisms via Suisun (or Montezuma) Slough? This report describes results of one part of the study that analyzed the distribution and tidal behavior of zooplankton in and around Grizzly Bay.

Methods

Samples were taken during two field surveys on May 25-26, 2000 (Cruise A) and June 1-2, 2000 (Cruise B). We used R/V Turning Tide in the channel near the reserve fleet, R/V Compliance in the shallows of Grizzly Bay, and R/V Holly Day Barnett in Montezuma and Suisun sloughs (Figure 1). Zooplankton samples were taken hourly using submersible pumps, alternating with sampling for larval fish using towed nets (W. Bennett in prep.). Samples were taken either at ~1 meter depth at shallow stations, or at deep stations by lowering and raising pump intakes through the water column. During the second field survey, samples were taken near-surface and near-bottom at the reserve fleet.

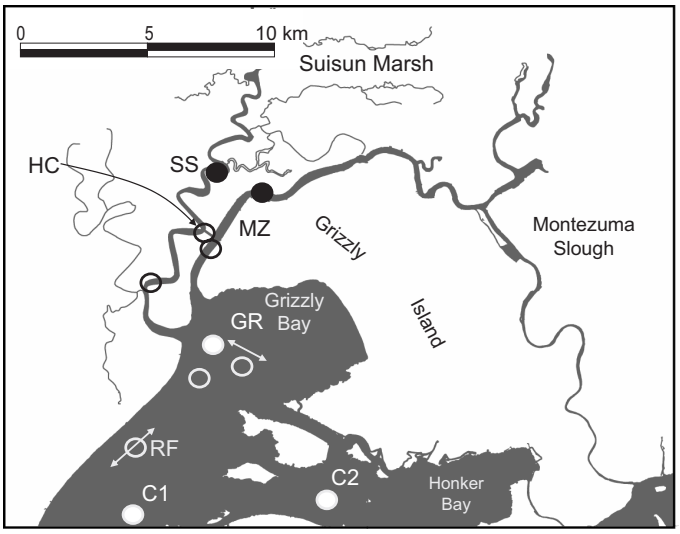

Figure 1 Map of Suisun Bay with sampling locations in this study (arrows or labeled open symbols) and routine zooplankton monitoring stations (solid circles). Current monitoring stations are indicated by open circles. Stations are: MZ=Montezuma Slough (routine sampling, sampling for this study, and ADCP); HC=Hunter's Cut (sampling for this study and ADCP); SS=Suisun Slough; GR=Grizzly Bay (all three); RF=Reserve Fleet (sampling for this study and ADCP); and C1 and C2, channel stations (routine zooplankton monitoring).

Twelve-volt submersible bilge pumps (Rule brand, 2,000 gph on Turning Tide, 1,500 gph on the other boats) discharged through a hose to a manifold with an electronic flowmeter calibrated by timing the filling of a bucket. The discharge flowed into a 35 Fm mesh, 30-cm diameter plankton net. Samples were concentrated into sample jars and preserved with ~5% formaldehyde. The pump on R/V Compliance broke during Cruise A, so remaining samples were taken by 3-minute subsurface net tow with the same plankton net, with an estimated volume filtered of 11 m^3. These data were treated separately in the analyses.

In the laboratory, subsamples of each plankton sample were taken with a piston pipette and the organisms in the subsample were identified to species (if possible) and counted. In most samples the small cyclopoid copepod *Limnoithona tetraspina* was most abundant, and it was counted in a single subsample. Additional subsamples were taken to obtain adequate counts of less abundant species of interest.

Data for only the most abundant species were analyzed. Analyses of vertical distribution and its dependence on tidal velocity (at station RF for cruise B only) followed the methods of Kimmerer and others (2002). Abundance was also plotted against tidal velocity for all stations on both cruises to determine any tidal pattern. Spatial distributions of zoop-

lankton were confounded by their responses to salinity; most of the common species discussed here are most abundant in or landward of the Low-Salinity Zone (Kimmerer 2002), so spatial patterns may have arisen due only to the salinity gradient. We therefore calculated the overall salinity distribution using all data for each species on each cruise. We fitted a nonparametric spline curve to the data using generalized additive models (Venables and Ripley 1997), which produces a curve without any pre-defined shape. Residuals from these curves were then used to investigate differences among stations using analysis of variance (ANOVA).

To provide some longer-term context to this study, we analyzed data from the IEP long-term zooplankton monitoring program (Orsi and Mecum 1986) for spatial patterns among stations in and near Grizzly Bay. As described above, differences among stations were confounded with differences due to salinity. We therefore conducted a similar spline analysis as above using all data for each survey on which data were available from all 5 selected stations. Residuals from that analysis for the 5 stations were then summarized graphically for comparison.

Results and Discussion

Copepods were by far the most abundant taxa in the samples, although mysids were also moderately abundant. The small cyclopoid copepod *Limnoithona tetraspina* in all life stages made up 94% (median; 10^{th} and 90^{th} percentiles were 85% and 100%) of the total abundance in all samples. Harpacticoid copepods were next most abundant but are not discussed further here because they include more than one species and may have come from different habitats. Moderately abundant species included the copepods *Eurytemora affinis*, *Pseudodiaptomus forbesi*, and *Sinocalanus doerrii*.

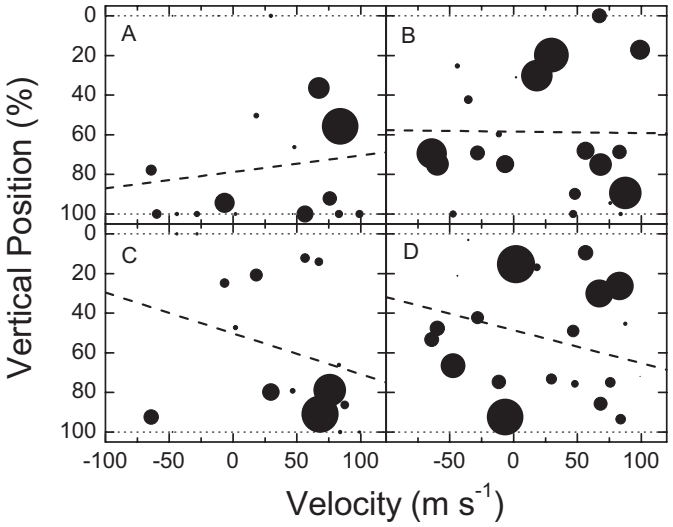

Figure 2 Vertical distribution of common species as percent of water column depth (surface to bottom) vs. tidal velocity for Cruise B at station RF. Size of symbols represents total abundance in the water column. A. Total mysids (max. 151 m-3); B. *P. forbesi* copepodites and adults (max. 762 m-3); C. *S. doerrii* copepodites and adults (max. 306 m-3); D. *L. tetraspina* copepodites and adults (max. 60,000 m-3). Dashed lines indicate non-significant regressions weighted by the square root of abundance.

Vertical position was determined only at the Reserve Fleet (station RF) on Cruise B. Results from that analysis were similar to those obtained for this region during the Entrapment Zone studies (Kimmerer and others 2002). Vertical position was not strongly related to tidal velocity, and mysids tended to be more abundant close to the bottom, by day and by night (Figure 2). The vertical positioning by mysids (Figure 2A) may result in retention in this region of the estuary because of stratification and gravitational circulation in Carquinez Strait (Kimmerer and others 2002). The lack of migration by copepods in this region could be due to low statistical power with a small range of tidal velocities, but it is also possible that copepods are retained through exchange with the shoals rather than through processes occurring only in the channels.

Abundance was also not related to tidal velocity (Figure 3). This means that these taxa at least were not going to the bottom in any great numbers on a tidal cycle. There was also no evidence of a diel effect on either abundance or vertical position (not shown). These results are also consistent with those from the Entrapment Zone study in this region (Kimmerer and others 1998).

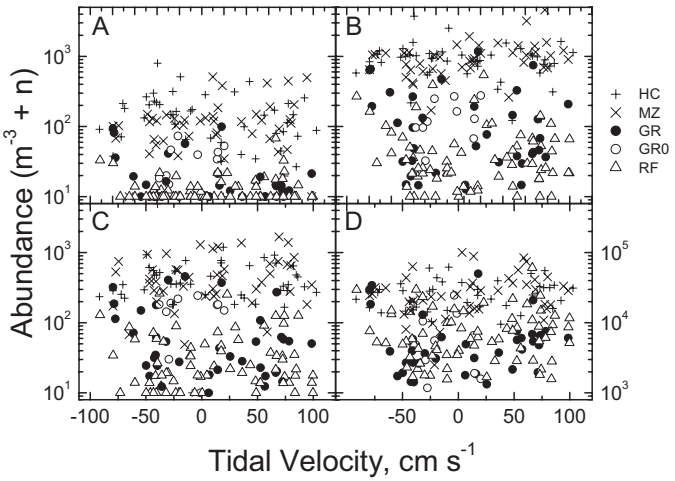

Figure 3 Abundance of common copepod species (copepodites and adults; n=10, except n=1,000 in D) vs. velocity for all samples. A. *E. affinis*; B. *P. forbesi*; C. *S. doerrii*; D. *L. tetraspina*. Symbols represent sampling stations; open circles labeled GR0 are samples from the Grizzly Bay station taken with a net (that is, uncertain volume filtered).

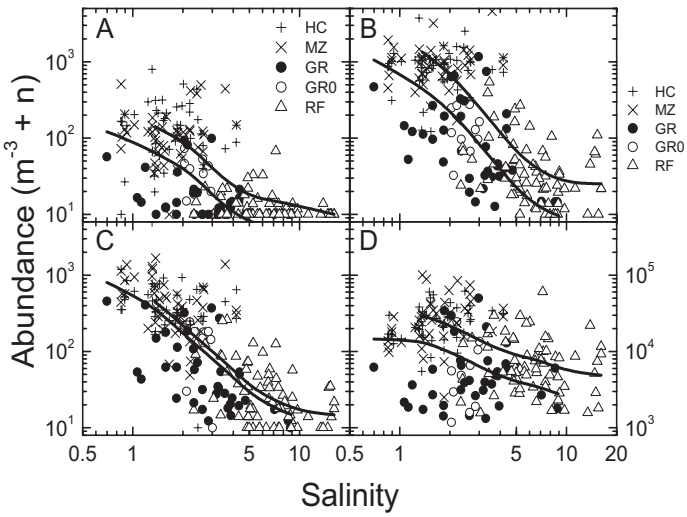

Figure 4 Abundance of common copepod species (copepodites and adults; n=10, except n=1,000 in D) vs. salinity for all samples. A. *E. affinis*; B. *P. forbesi*; C. *S. doerrii*; D. *L. tetraspina*. Lines are nonparametric cubic splines fit to the data using a generalized additive model (Venables and Ripley 1997) separately for cruises A (lower curve) and B. Symbols as in Figure 3.

Table 1 Residual abundance of common taxa from generalized additive model in salinity (curved lines in Figure 4). Stages are either adults and copepodites (A&C) or nauplii (N). Analysis of variance of residual abundance with location and sampling date/time as factors. The p values are given for the overall analysis; values for each station are the station means.

Species	*Stage*	*p*	*Hunters Cut*	*Montezuma*	*Grizzly Bay*	*Reserve*
L. tetraspina	A&C	<0.0001	0.15	0.18	-0.35	0.02
	N	<0.0001	0.15	0.22	-0.35	-0.02
E. affinis	A&C	<0.0001	0.32	0.24	-0.53	-0.03
	N	<0.0001	0.23	0.02	-0.12	-0.13
P. forbesi	A&C	<0.0001	0.19	0.23	-0.37	-0.04
	N	<0.0001	0.35	0.24	-0.51	-0.08
S. doerrii	A&C	<0.0001	0.18	0.24	-0.38	-0.04
	N	0.004	0.20	0.17	-0.20	-0.17
Mysids	—	<0.0001	0.47	-0.01	-0.38	-0.08

Abundance declined with increasing salinity (Figure 4), and there was a distinct salinity gradient among the stations from low salinity at the two stations in the entrance to Suisun Marsh and highest salinity at the reserve fleet. However, abundance of all common taxa in the samples from the Grizzly Bay station appeared to be consistently lower than expected on the basis of salinity, either including or excluding the samples collected by net with estimated volume filtered (Figure 4). This low abundance was borne out by the analysis of variance that showed that all common taxa were less abundant in Grizzly Bay, and more abundant at other stations, than expected on the basis of salinity (Table 1). This analysis did not change if the samples taken by net at station GR were excluded. This result was therefore likely not an artifact of sampling but rather a real difference in abundance.

This finding was not borne out by analysis of the long-term monitoring data, which showed gradients in abundance between Suisun Marsh, through Grizzly Bay, and into Suisun Bay for the same species (Figure 5). The calanoid copepods were generally more abundant in the marsh and *L. tetraspina* more abundant in the open waters than expected

based on the salinity patterns (Figure 5). Note that, except for *L. tetraspina*, the patterns of abundance between the marsh stations and Grizzly Bay were similar (Figures 4 and 5).

The difference in these results could have been due simply to the difference in time scale of the respective sampling programs; for example, during the Grizzly Bay study a persistent pattern of abundance may have existed that was not typical in the longer term. However, the sampling pattern was also different, in that we sampled in the northern channel of Suisun Bay (near station RF) which was not commonly sampled during the zooplankton monitoring studies after 1993. This channel had a higher abundance of zooplankton than the main channel during the 1998 Entrapment Zone study (Kimmerer and others 1998). Thus, the apparent inconsistency between results of our study and the long-term monitoring may be merely an artifact of the choice of sampling stations.

Three principal conclusions arise from this part of the Grizzly Bay study. First, the shallow region as represented by station GR was not marked by high abundance of any zooplankton species or life stage. Zooplankton production is the product of biomass and specific growth rate, which is largely a function of temperature and food concentration (Hirst and Bunker 2003). Although we did not measure growth rate or food concentration, there is no reason to suppose that specific growth rate was markedly higher in Grizzly Bay than elsewhere. Thus, zooplankton production was also depressed at that location.

Second, the low abundance in Grizzly Bay remains unexplained. Although it is conceivably due to predation by small fish over the shoals (Kimmerer 1991), this would not explain the similar pattern of abundance of all species and life stages of copepod (Table 1). For example, *L. tetraspina* may be less available as food for young fish than other species (Nobriga 2002) because it is much smaller and presumably less detectable. This spatial pattern was not due to vertical patterns of abundance in the channels, since copepods were vertically randomly distributed at least at the reserve fleet station during Cruise B (Figure 2).

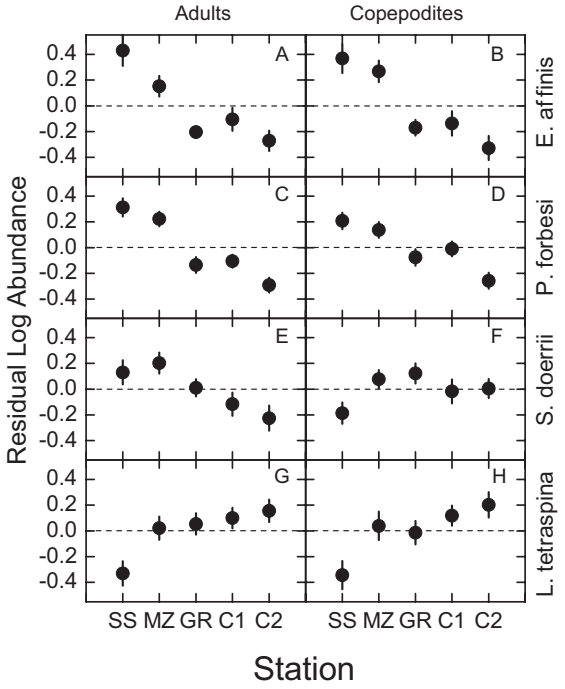

Figure 5 Abundance of common copepod species in samples from routine zooplankton monitoring survey in stations in and near Grizzly Bay from 1989 through 2002. Data are residuals from a smoothed relationship between log of abundance (+10 for most species, +1,000 for *L. tetraspina*) vs. log of salinity for all sampling dates with data from all 5 of these stations. Stations are shown in Figure 1. Species are in the same order as in Figures 3 and 4, but adults and copepodites are shown separately. Symbols indicate grand mean residuals and 95% confidence limits of the mean.

Third, the higher abundance of most taxa in the Suisun Marsh stations (Figures 4 and 5) suggests some mechanism either for position maintenance or higher net population growth rate there. It also suggests that the marsh channels may have persistently higher zooplankton abundance than Grizzly Bay (Figure 5), which could suggest an important role of this region in rearing young fish. This is not strictly speaking an effect of SWH, though, because much of the marsh volume (and all of that sampled) is in channels rather than tidal marsh. However, it does suggest that exchange between the marsh and the open water could be important in maintaining populations of zooplankton in the Low-Salinity Zone, at least in northern Suisun Bay and Grizzly Bay.

The next step is to calculate fluxes of zooplankton between the regions sampled, and use those fluxes to estimate net mortality rates in Grizzly Bay. However, the complexity of the 3-dimensional flow field in this region precludes simple calculations as have been done previously

based only on current velocities and abundance (for example, Kimmerer and McKinnon 1989). Therefore 2-dimensional or 3-dimensional hydrodynamic modeling will be needed to sort this out.

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The Invasive New Zealand Mud Snail Reaches the Central Valley Watershed[1]

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The New Zealand mud snail (*Potamopyrgus antipodarum*) is a tiny, invasive snail native to freshwater lakes, streams, and estuaries of New Zealand. The mud snail was unintentionally introduced to Europe, Asia, and North America. It was first detected in the US in 1987 in the Snake River, Idaho. Populations of mud snails are now present in nine western states (California, Oregon, Idaho, Montana, Wyoming, Arizona, Nevada, Colorado, and Utah). In California, mud snails are found in the upper and lower portions of Owens River near Bishop (i.e., Crowley Reservoir, Bishop Creek Canal, and Hot Creek). Mud snails were found in upper Putah Creek (Solano County, CA), west of the city of Davis in October 2003, and in the Mokelumne River (San Joaquin County, CA), east of the city of Lodi in December 2003.

Identification and Life History

These tiny snails are 1 to 6 mm long, have a cone-shaped shell with 5 to 6 whorls, and are light brown to black in color (Figure 1). They have an operculum or plate that acts like a door to seal the body off from the outside environment. This operculum protects them from predation and allows them to survive short periods of desiccation. Not all

1. This article was published in *Pisces* (Vol. 32, No. 4, Winter 2003-04).

snail species have an operculum, and it is usually missing on dead mud snail shells.

New Zealand mud snails may be confused with other small, relatively indistinctive snails, including other introduced snails and poorly described native snails. Visit http://www2.montana.edu/nzms/ or http://www.esg.montana.edu/aim/mollusca/nzms/id.html for photos of mud snails and comparisons to a few snail species. However, keep in mind that this comparison is not complete and was made for Montana, Idaho, and Wyoming, not California.

In New Zealand, both sexual and parthenogenetic populations occur. In the western US, all known mud snail populations are parthenogenetic, meaning it only takes one female snail to start a population. Mud snails carry 20 to 120 embryos at a time and bear live young. Reproduction can occur year-round, depending upon water temperature and food availability, but most reproduction occurs March through October. Their lifespan is about one year.

New Zealand mud snails can occur in rivers, springs, reservoirs, lakes, and estuaries (up to 17-24 ppt salinity) and in silt, sand, cobble, riffle, run, and vegetated habitats. They prefer habitats with constant flow and temperatures, but they can tolerate a wide range of temperatures (0 to 80 °F). Higher densities of mud snails occur in systems with high primary productivity. They eat diatoms, plant and animal detritus, and attached periphyton. Mud snails have no known predators in the western US. Some fish feed on these snails, but most mud snails pass through the digestive tract unharmed (the mud snails close their operculum as they are passed through the gut).

Figure 1 New Zealand mud snails have 5 to 6 whorls, are light to dark brown, and are up to 6 mm long. Photo by DL Gustafson.

Figure 2 Numerous New Zealand mud snails cover a rock in DePuys Springs Creek, Montana. Photo by DL Gustafson.

Impacts

New Zealand mud snails can occur in extremely high densities, blanketing the substrate (Figure 2). Densities have been reported to range from 10,000 to 50,000/m^2 in the Owens River and from 10,000 to 500,000/m^2 in the mid-Snake River. In rivers and streams where mud snails occur in high densities, caddisfly, stonefly, and mayfly densities dropped as mud snail densities increased. The change in relative abundance of aquatic insects may result in food web impacts, when the invertebrates that serve as food resources for fish (especially trout and other native fish species) are reduced. Mud snails appear to be of little nutritional value to fish, as most pass through the digestive tract of fish undigested and unharmed. The most likely economic impact will be to the trout fishing industry if trout growth rates and populations decline. Its ecological impacts may be substantial as well.

Preventing Spread

Mud snails are easily spread via contaminated equipment, particularly waders and boots. Mud snails can close their operculum and survive for several days in a moist environment, such as inside waders, in mud on boots, in kayaks and rafts, or in boat livewells and cooling systems. Therefore, to prevent the spread of New Zealand mud snails and other invasive species, it is critical to thoroughly clean all gear after leaving one water body and before entering another one.

Here are some ways to kill New Zealand mud snails that cling to your gear:

- In hot weather with low humidity, leave gear in direct sunlight and let dry completely. At temperatures above 30 °C (86 °F), dry gear for at least one day. At temperatures above 40 °C (104 °F), dry gear for at least 2 hours.

- Soak waders, wader boots, and other equipment in hot water (120 °F) for at least 1 minute. The simplest method is to fill your tub with hot tap water (most water heaters are set at 130 °F) and soak your gear for at least 5 minutes or until the water cools.

- Place gear in the freezer for several hours or overnight.

- Use separate sets of gear if cleaning your gear between visits to different water bodies is not a realistic option.

- Do not take it for granted that your equipment is clean even if you cannot see a mud snail. Remember, these snails are very tiny. Newly released snails are white to transparent and are difficult to see.

- Remember to remove all vegetation, debris, and mud from your boat, boat prop and trailer, and clean your boat (including livewells and intakes) with hot water or let it dry for several days in direct sunlight. Not only does this help prevent the spread of mud snails, it also prevents the spread of aquatic weeds and other invasive organisms.

- Mud snails can be spread in the innards of fish. Remove the stomach and digestive tract from any harvested fish at the site you catch them. Dispose of the materials in closed receptacles on site if possible. Dispose of any fish remains at a sanitary landfill.

- And lastly, do not visit the Putah Creek or Mokelumne River sites. Remember to clean your gear thoroughly after visiting the Owens Valley area.

On December 16, 2003, the California Fish and Game Commission voted to close all fishing in Putah Creek from Monticello Dam on Lake Berryessa to, and including, Lake Solano for 120 days to prevent further spread. During this time, staff from state and federal agencies will delineate the population in Putah Creek, inspect other waterbodies for New Zealand mud snails, and determine a course of action.

Report Sightings

While fishing, sampling, checking gear, or moving field equipment to a new location, take a moment to look for snails on your gear, and nearby rocks, debris, etc. If you find snails blanketing a surface that resemble New Zealand mud snails, collect 10 to 20 live snails and save them in stream water or preserve them in 95% ethanol. For identification purposes, do not preserve them in a lower concentration of ethanol, in formaldehyde, or in isopropyl alcohol. Record the county, water body and specific location within the water body, latitude and longitude, collection date, names of field collector(s), and estimated mud snail density. Compare your snails to the pictures at http://www.esg.montana.edu/aim/mollusca/nzms/id.html to confirm that they resemble New Zealand mud snails. Contact David Bergendorf with the above information (e-mail: david_bergendorf@fws.gov; phone: (209) 946-6400 ext. 342), and he will advise you on how to proceed. And remember to clean your gear after leaving the water!

For more information about New Zealand mud snails, visit http://www.esg.montana.edu/aim/mollusca/nzms/ or visit http://www.protectyourwaters.com/hitchhikers/ and follow the links for the New Zealand mud snail.

Assessment of Mitten Crab (*Eriocheir spp.*): Monitoring Methods and Habitat Preference in the San Francisco Estuary

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Development of a monitoring program for age-1+ Chinese mitten crab (*Eriocheir sinensis*) was continued in summer 2003. This was the third year of a 3-year study that was one component of an IEP Work Plan prepared by the US Fish and Wildlife Service (USFWS) and the California Department of Fish and Game (DFG) (Webb and Hieb 2001). The intent of the monitoring program was to identify upstream rearing areas, as well as fast and inexpensive methods to detect age-1+ mitten crabs. Due to the previously reported variation of sampling methods and habitat types inhabited by mitten crabs, we tested two general hypotheses in 2003:

1. There is no relationship between measurable habitat parameters and age-1+ mitten crab abundance.

2. There is no difference in the efficacy of different detection methods for age-1+ mitten crabs.

We conducted surveys employing several different methods throughout summer 2003 to assess the relative effectiveness of various detection methods and to relate physical habitat parameters to the relative abundance of age-1+ mitten crabs. At each site, quantitative habitat characteristics were measured, including salinity, electrical conductivity, temperature, stream velocity, stream depth, and intertidal bank height. Difficult-to-measure variables—such as vegetation characteristics, substrate type and soil texture—were estimated so that descriptive statistics could be used later to suggest likely relationships between variables that might warrant further investigation.

Background

The presence of the Chinese mitten crab in the San Francisco Bay and Sacramento-San Joaquin River Delta (San Francisco Estuary) was first confirmed in 1994 from crabs collected by shrimp trawlers in South San Francisco Bay (Cohen and Carlton 1995). Since that time the Chinese mitten crab has become a widespread species in the estuary and its watershed. Monitoring data indicate that the Chinese mitten crab population has declined since 1999 (Rudnick and others 2003), but this decline is unlikely to be permanent.

Evidence from European introductions indicates that mitten crab populations can be highly variable annually and cyclic over decades (Gollasch 1999, Clark and others 1998). European populations have rebounded after each decline, indicating that multi-year decreases are not necessarily linked to a permanent population decline (Rudnick and others 2003). Individual female mitten crabs produce between 250,000 and 1,000,000 eggs in a brood (Cohen and Carlton 1995) making it unlikely that mitten crabs will be extirpated from any large estuary by natural processes.

Ecology of Chinese Mitten Crabs in the San Francisco Estuary

The Chinese mitten crab is a catadromous species that rears in fresh water and spawns in saltwater (Veldhuizen and Stanish 1999). Eggs hatch from late winter to early summer (Cohen and Carlton 1995) and mitten crabs develop through 5 larval stages, culminating in a megalopae stage (Veldhuizen and Stanish 1999). The megalopae settle to the substrate in brackish water and the young crabs migrate upstream to rear, primarily in brackish sloughs and freshwater areas immediately upstream of brackish water (Hieb, personal communication 2003). In their second year, many crabs migrate further upstream to freshwater rearing areas that may be over 100 km from where they hatched (Hieb, personal communication 2003). It is not yet known why mitten crab megalopae select particular streams or rivers to rear in. In the late fall, adult crabs from 2 to 5 years of age migrate downstream to salt water where they reproduce and die (Rudnick and others 2003). While much is known, the life cycle of the Chinese mitten crab in the San Francisco Estuary is not yet fully understood.

Mitten Crab Ecology in the San Francisco Estuary

USFWS employees began investigating the mitten crab after it was first confirmed in the San Francisco Bay in 1994. Rudnick and others (2003) summarize research conducted on the abundance, ecology, and population characteristics of mitten crab in the San Francisco Estuary. Since 1994, researchers have employed a variety of mitten crab sampling methods including baited traps, passive traps, and direct observation. However, the relative ability of different sampling methods to detect crabs is unknown and few methods have met the desirable criteria of being inexpensive and fast to deploy and retrieve.

Currently there is insufficient long-term data to accurately predict mitten crab year-class size before the downstream reproductive migration begins (Rudnick and others 2003). In addition, because the efficacies of sampling methods are unknown, it is difficult to accurately estimate the relative abundance of mitten crabs in any particular area. From the data available it appears that mitten crab population has varied greatly in the estuary from relatively low levels to very high levels, with a peak in 1998 (Hieb, personal communication 2003). This pattern of highly variable population size is similar to patterns seen in European mitten crab populations (Gollasch 1999, Clark and others 1998).

Abbreviated Methods

In 2003, development of a mitten crab monitoring survey consisted of sampling studies at randomly selected sites and a sampling methods comparison at sites with known mitten crab population. Any observations made by researchers in the course of sampling, even if the observation was not a direct result of the method used, were recorded as an observation associated with that sampling method. For example, when a researcher, who was fishing, noticed a mitten crab walk by, the size of the crab was estimated and recorded as observed during fishing.

Sampling at Randomly Selected Sites

In order to assess the habitat preferences of mitten crabs, different sampling methods were used at randomly selected sites, from general areas where mitten crabs had been reported in previous years (USFWS 2003). Both passive and active sampling was conducted at sites primarily within the Sacramento-San Joaquin River Delta (Delta).

Passive habitat sampling was conducted in three general areas between June 10 and August 14, 2003. Passive habitat traps were based on the design of the artificial shelter traps used by Veldhuizen (2003) and consisted of 12 pieces of 16-cm long, 5-cm wide poly vinyl chloride (PVC) pipe lashed together to form a PVC pipe and plastic mesh cube with one open side. Traps were placed in tributaries of the Sacramento River (Dry Creek, Feather River, and Horseshoe Bend), the San Joaquin River (Shiloh fishing access and Caswell Park), and San Pablo Bay (Tolay Creek and northern Napa-Sonoma Marsh). Traps were placed in streams for at least 1 week prior to being checked, to allow resident mitten crabs to become acclimated to the trap presence. These traps were checked every week. In addition to the three primary sampling regions, one trap (already present) was checked twice in Coyote Creek, a South Bay tributary.

The first phase of active sampling (June 3 to July 10, 2003) consisted of walking transects and conducting a visual survey for mitten crabs. A transect was defined as a 20-m long line on one side of a stream. At each site the sampler would walk the 20 meter transect slowly with a net in hand, observing and looking from side to side for any crabs within the transect.

The second phase of active sampling (July 15 to August 14, 2003) consisted of baited fishing using a Kershaw's Crab Grabber and a snag trap. At each site, fishing was conducted with 2 fishing poles, 1 pole for each type of trap, for a total of 30 minutes. Sardine (*Sardonella longiceps*) and chicken liver were alternately used as bait in the crab grabber and the snag trap.

Researchers recorded the sex and carapace width of all mitten crabs caught during sampling. The carapace width was estimated for any crabs that were observed, but not caught.

Comparison of Methods at Sites with Known Mitten Crab Populations

A supplemental study was conducted from August 18 to August 30, 2003, to examine the efficacy of several sampling methods. The most promising sampling methods—as determined by literature reviews, USFWS experiences, and consultation with other biologists—were selected for trials at sites with known age-0+ mitten crab populations. Sampling was conducted in DFG's Ringstrom Unit in northern Napa-Sonoma marsh and Coyote Creek in South Bay because no crabs were found in or upstream of the Delta during summer sampling.

When samplers arrived at the site, the passive habitat traps were checked for crabs. After checking traps the samplers began active fishing, using 2 fishing poles rigged with baited crab grabbers. One crab grabber was baited with a threadfin shad (*Dorosoma petenens*) and the other crab grabber was baited with chicken liver and each was fished for a 30-minute period. When the fishing ended, baited stakes were placed to attract crabs. At each site 3 stakes were used. Each stake was baited with chicken liver, threadfin shad, or sardine. Stakes were hammered into shallow stream banks so that the baits were submerged by 5 to 10 cm of water, but were still visible. Once the stakes were placed the sampler would step back far enough to assure that their shadow was not covering the baits or nearby water, and timing began. The sampler then recorded any mitten crabs that approached or fed on baited stakes for 30 minutes. The carapace widths (CW) of the all crabs were visually estimated in mm.

Analysis of Results

All statistical analyses were conducted using SPSS 11.5 statistical analysis software. Data from randomly selected sites were analyzed using step-wise linear regression, as described in McClave and Sincich (2000), to fit the best model to the data. Linear regression was used to model the effect of habitat parameters on passive habitat trapping observation per sampling effort (OPSE), visual transect OPSE, and baited fishing OPSE.

Analysis of Variance (ANOVA) was used to analyze data, from method comparison trials, at the two sites known to be populated with mitten crab. A one-way ANOVA was used to compare group mean OPSE between trapping methods and group mean crab size between different trapping methods.

Results

Results at Randomly Selected Sites

Of 55 passive trapping samples conducted during this phase, 24 mitten crabs were observed. Passively trapped crabs ranged from 7 to 48 mm in CW, 71% were male, 21% were female, and 2% were unknown.

Table 1 Comparison of observations made during different mitten crab (*Eriocheir sinensis*) sampling methods at randomly selected sites in the San Francisco Estuary

Sample dates	Observation method	Observations/ samples	Mean carapace width (mm)	Minimum size	Maximum size (mm)	Number of males	Number of females	Number of not sexed
6/3/03-7/10/03	Transect	2/58	25.5	24	27	0	2 (molts)	0
7/15/03-8/14/03	Fishing (crab grabber)	1/44	55	n/a	n/a	n/a	n/a	1
7/15/03-8/14/03	Fishing (snag trap)	0/44	n/a	n/a	n/a	0	0	0
6/3/03-7/10/03	Trapping	24/54	19	10	48	16	6	2

Table 2 Comparison of mitten crab (*Eriocheir sinensis*) observations made during different sampling methods at sites with known populations of mitten crabs in the San Francisco Estuary (August 18 to August 30, 2003).

Observation Method	Observations/ Samples	Mean carapace width (mm)	Minimum Size (mm)	Maximum Size (mm)	Number of Males	Number of Females	Number of Not Sexed
Trapping	10/13	18	7	34	7	3	n/a
Fishing (crab grabber)	8/16	35	10 (dead)	60	2	2	4
Stakes	7/17	35	10 (dead)	60	n/a	n/a	7

Of 58 transects sampled only 2 yielded traces of mitten crab. In 1 transect pieces of a dead mitten crab were found and in the other transect a mitten crab molt was found. Of 45 baited fishing samples, using a crab grabber on one pole and a snag trap on the other pole, only 1 crab was observed feeding on bait. Sample size was insufficient to investigate the relationship between the crabs observed feeding and any measured habitat variables.

Table 1 displays summary statistics on the efficacy of different sampling methods employed at randomly selected sites between June 3 and August 14, 2003. No statistically significant relationships were found between habitat parameters and mitten crab abundance (" =0.10). The relationship between salinity and passive trapping OPSE was highly significant (p = 0.002), but salinity alone explained little of the variation in OPSE around the mean (R^2 =0.18) and was influenced by the large number of relatively low salinity samples with no crabs.

Results of Method Comparison at Sites with Known Mitten Crab Populations

When sampling methods were compared, passive habitat traps yielded the highest mean OPSE, followed by fishing with 2 crab grabbers and baited stake observation. Passive trapping averaged 0.8 OPSE, fishing with 2 crab grabbers averaged 0.5 OPSE, and the stake and watch method averaged 0.4 OPSE. An ANOVA performed on these differences, however, did not reveal statistically significant differences in the group mean OPSE between observation methods (" = 0.10).

The mean size of crabs caught by the different methods varied. Passive trapping tended to catch smaller crabs (mean CW = 18 mm) when compared to the other two methods (Table 2). The mean size of crabs observed by fishing and the stake and watch method was identical (mean CW =35 mm). An ANOVA performed on these results, however, did not reveal statistically significant differences in the group mean crab size between observation methods (" = 0.10).

Mitten crabs did exhibit an apparent bait preference that was not consistent between sampling methods. Crabs observed while using the baited stakes method appeared to favor shad and sardines over chicken liver (Figure 1). A one-way ANOVA test confirmed that the OPSE for shad and sardine was significantly higher than the OPSE for chicken liver (p = 0.000, p = 0.005 respectively). In contrast, fishing with crab grabbers resulted in an identical number of crab observations when chicken liver or shad was used as bait.

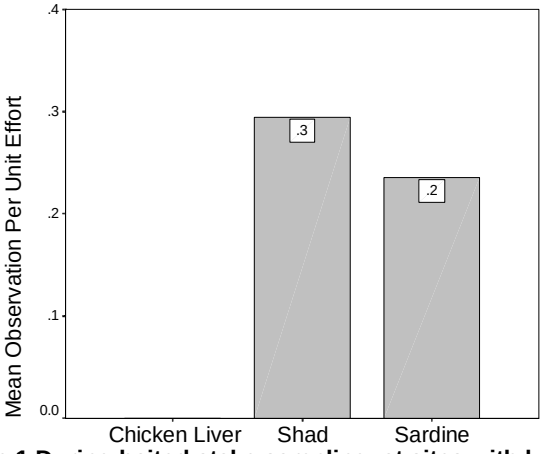

Figure 1 During baited stake sampling, at sites with known mitten crab (*Eriocheir sinensis*) populations, crabs were preferentially attracted to stakes baited with shad and sardine and were not attracted to chicken liver (August 18-August 30, 2003).

Discussion

General monitoring methods including mitten crab counts at fish salvage facilities and citizen reports to the mitten crab reporting system indicate that the 2003 adult mitten crab population in the San Francisco Estuary was substantially lower than the historic peak in 1998 and the lowest since 1996, when crabs were first collected in the Delta (Hieb, personal communication 2003, USFWS 2003). It is equally evident that mitten crabs have not been extirpated from the San Francisco Estuary.

The cause of the large annual variability in the San Francisco Estuary's mitten crab population size is unknown, but authors have speculated about causes of similar population variation in Europe. For example, in the Thames River estuary in England, a large increase in the relative population of mitten crabs has been observed since 1992; prior to 1992, the population had been relatively constant since the 1970s (Clark and others 1998). The increase is believed by some to be due to improved mitten crab settlement coinciding with several years of local drought (Atrill and Thomas 1996). The San Francisco Estuary's mitten crab population will likely be highly variable from year to year as seen in other regions where they have been introduced (Rudnick and others 2003).

The current study confirms the wide range of environmental conditions in which mitten crabs are found (Table 3). This finding agrees with the observations of other researchers (Rudnick and others 2003, Veldhuizen 2003). Given the small number of crabs collected and observed over the summer of 2003 and the variability of habitats in which mitten crabs were found, it is not surprising that no meaningful or significant relationships could be found between quantifiable habitat parameters and relative mitten crab abundance.

A statistically significant positive relationship was found between salinity and passive trapping OPSE, but little of the variation around the central OPSE trend could be explained by variation in salinity. This finding appears to be driven by the large number of samples in freshwater streams with no crabs and few samples in brackish water with crabs. There are several possible interpretations of this finding, but the small sample size limits the ability to make any definitive inference. The low variability explained probably indicated that both salinity and passive trapping OPSE are related to some other variable, such as proximity to the San Francisco Bay, food resources, or other unmeasured habitat parameters. Passive traps also selectively catch smaller mitten crabs, which are more likely to be present in brackish water (Hieb, personal communication 2003).

When sampling methods were directly compared, passive habitat trapping had the greatest success—in part because it targets smaller, more abundant crabs—followed by fishing with crab grabbers and the baited stakes method. While not statistically significant, there did appear to be a clear trend in the efficiency of different observation methods. It is also worth noting that the baited stakes and fishing methods take approximately 45 minutes per sample, compared to approximately 10 minutes per sample to check passive traps and risk of loss during prolonged deployment. The baited stakes procedure also limits crab data collected since crabs are not actually caught. Other studies have also

Table 3 Ranges of environmental parameters in which mitten crabs were found during June 3-August 27, 2003, sampling in the San Francisco Estuary

Measurement	*Temperature °C*	*Salinity (ppt)*	*Electrical conductivity (mS)*	*Stream width (m)*	*Stream depth (cm)*
Maximum	28.2	22.2	1,570	30+	150
Minimum	20.9	0.7	5.5	2.5	36
Mean	23.2	7.6	611.4	11+	81

indicated that passive habitat trapping is the most likely method to observe mitten crabs, when compared to other available methods (Veldhuizen 2003). One caveat of using passive habitat traps is that sampling results are biased toward catching smaller mitten crabs. On the other hand smaller (younger) crabs may be more numerous, improving detection probability and the detection of smaller crabs would result in 1-2 years for decision-makers to adjust programs to manage the downstream migration of the sampled year class as adults.

Observations during baited stake sampling suggested that shad was the preferred bait, followed by sardine while chicken liver was not sought by mitten crabs. These findings contrast with data from crab grabber fishing, which suggests that mitten crabs feed on chicken liver and shad equally. There are at least two possible explanations for the contradiction in these data. The most likely explanation is that the sample size was so small that any detected differences are simply an artifact of stochastic feeding differences. Another possibility is that crabs in deep water are less particular about feeding. The fact that average fishing water depth was 60 cm compared to 19 cm for baited stakes might have influenced the bait selection. Perhaps the greater risk of approaching bait in relatively shallow water is only attractive if the reward is shad or sardine.

Suggestions for Future Research

The results of this three-year study are inadequate to suggest the best methods to detect age-1+ mitten crabs. Future sample method comparison and bait preference studies for age-1+ mitten crabs should be carried out in a controlled environment to elucidate differences in efficacy. Future monitoring efforts, in any area as large as the San Francisco Estuary, could use passive habitat traps to efficiently gauge relative abundance of age-0+ crabs with less then 48 mm carapace width. If systematic monitoring is carried out regularly, at many locations throughout the Delta, over a period of years it should be possible to predict year-class strength 1 to 2 years in advance of downstream migration of adults and potentially to correlate population size with water temperature, freshwater outflow, and other variables that may control year-class strength.

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Otolith Ageing of Age-0 Splittail: Techniques, Validations, and Limitations

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Introduction

Otoliths are an important tool for understanding fish life history and population dynamics. One of the many useful "markers" that can be obtained from otoliths is that growth increments are deposited daily by most young fish, allowing the determination of age and growth rates. As part of a study on the early life history of splittail, we are using otolith microstructural analysis to determine the growth rates of age-0 fish collected from different habitats throughout their entire distribution. Together with data on diet and environmental conditions, our ultimate goal is to test hypotheses that will improve our understanding of factors controlling the recruitment of young splittail.

Although the formation of daily increments in otoliths is widespread among young fishes, validation is still necessary for unstudied species. Further, the time of first increment formation can vary substantially among species, potentially adding significant error to age estimations. We have previously reported a preliminary validation of daily growth increments in the otoliths of age-0 splittail using marked fish (Feyrer and others 2001, 14:3:15). However, at that time we still did not know when the first increment was formed. We have since been able to examine the otoliths of

known-age fish to further validate daily growth increments, as well as demonstrate that the first increment forms at hatch. The primary purpose of this paper is to document these recent findings. We also want to share our techniques for preparing young splittail otoliths for examination, as well as the problems we encountered while developing these techniques. In addition to expanding our knowledge of an important native species, we hope that this account will help other researchers who are considering otolith studies on young cyprinids.

Otolith Function and Structure

Teleost fishes have three pairs of otoliths that function in balance and hearing. The three pairs are the lapillus (lapilli, pl.), sagitta (sagittae, pl), and asteriscus (asterisci, pl), and they differ in location, function, and morphology. Otoliths are in the vestibular apparatus (inner ear structure) of fishes. The inner ear structure in most bony fishes is basically made up of an upper section (pars superior) and a lower section (pars inferior). Typically, the pars superior regulates balance and equilibrium and contains the lapilli, while the pars inferior contributes to hearing and contains the sagittae and astersisci. Sagittae are usually the largest otoliths and are commonly used for aging studies. However, the otolith structure of ostariophysans (minnows, catfishes, and characins) differs substantially from that of other teleosts because these fishes have a special structure called the Weberian apparatus. In the simplest sense, the Webberian apparatus connects the inner ear structure of a fish to the air bladder, and is known to assist with high frequency hearing. For splittail, the result is a unique otolith morphology in relation to non-ostariophysans (Figure 1).

Lapilli are the largest otoliths in splittail and were considered the most suitable for our ageing studies. In the young splittail we have examined, the lapilli are typically shaped like small round stones that take on a somewhat heart-like shape in older fish. Sagittae, typically the largest otoliths in most bony fishes, are much reduced in size in splittail. Early sagittae are nearly round. Two projections, a rostrum and prorostrum, form in older fish and extend outward from an inner kernel. In the young fish we have examined, these projections are extremely delicate and fragile; it is nearly impossible not to break them. Asterisci are shaped like irregular little stone pancakes. They are flat on one side with a convex pattern of irregular growth on the other side. We have found that sagittae and asterisci are unsuitable for our ageing studies of age-0 splittail because of their delicate nature and apparent irregular growth patterns.

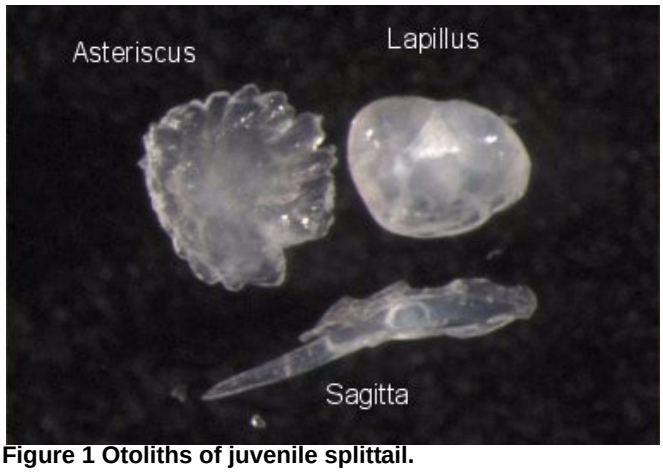

Figure 1 Otoliths of juvenile splittail.

Otolith Extraction and Mounting

Extraction and mounting of lapilli otoliths from juvenile splittail is quite easy and simple, with a little practice. We have obtained the best results for extraction with a modified open-the-hatch technique (Figure 2). With a sharp scalpel, we cut through the fish laterally, just above the eye extending to beyond the operculum. This cut piece can then removed to expose a dorsal view of the brain. With the brain tissue removed, lapilli are located in vestibules on either side of the brain cavity, just where it bottlenecks. The otoliths can be easily removed from the vestibules with fine forceps. We move the otoliths directly into a drop of 10% sodium hypochlorate solution (bleach) to clean off any attached tissues. The otoliths are then transferred from the bleach into a drop of water to rinse. Prior to placing the otoliths on a dry section of the dissecting tray for air drying, we rinse them in ethanol because it highly volatile and evaporates very quickly, minimizing the drying time. We mount the otoliths whole in CrystalBond wax mounting media on glass microscope slides (one otolith per slide). We place a small piece of the mounting media on a slide and heat it on a hot plate until it is soft and easily manipulated. It is important not to overheat the mounting media because it will bubble and eventually burn. It is also important to use the minimum amount of mounting media necessary to cover the otolith. This will prevent spending an excessive amount of time later during the polishing stage trying to grind through excessive overburden to reach the otolith. While the mounting media is still workable and gummy, the otolith is carefully placed into it so that it is positioned flat (exposing a sagittal plane) on the slide and is completely covered. Which side of the otolith is placed is down (left or right) does not seem to matter for our studies. Small dry otoliths have an amazing ten-

dency to enter flight when held with fine-tip forceps. Therefore to keep from losing otoliths, we actually transfer them from the dissecting tray to the slide by pressing down on the otolith with a dry finger, which apparently wedges the otolith within the ridges of your fingerprint, and carefully scraping them off the finger onto the mounting media with forceps or a probe. We have not lost a single otolith using this technique. The slide is then put aside to cool before preparation for reading.

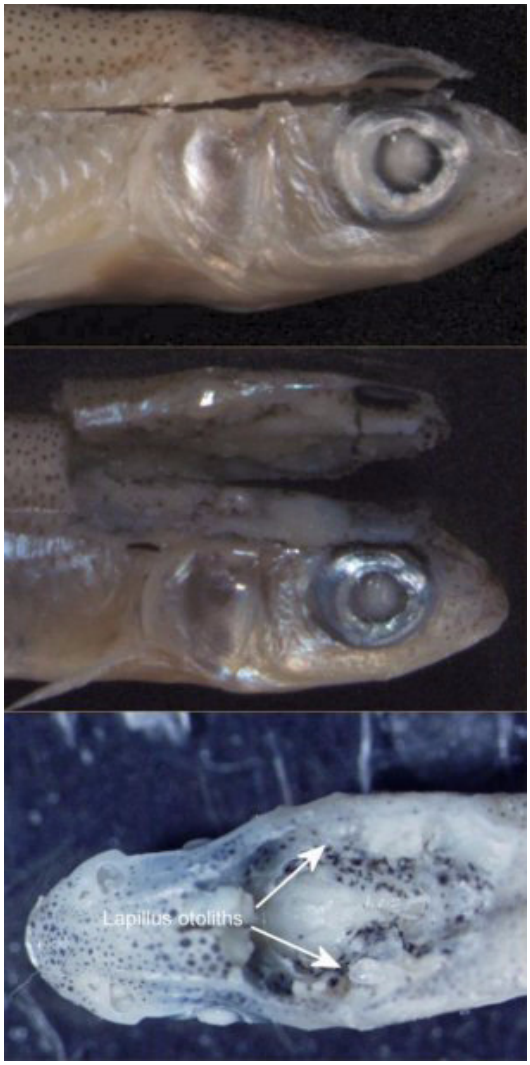

Figure 2 Figure 2 Basic methods for quick removal of juvenile splittail lapilli otoliths.

Extraction and mounting of otoliths from larval fish is somewhat more complicated. For extraction, what we have found to work best is to cut off the head of the larvae and then immerse it in bleach. Medicine droppers or similar devices work well for applying just enough bleach to completely immerse the head. After several minutes, the bleach will dissolve all of the surrounding tissues and only the otoliths will be left in the solution. Because all otolith pairs will be present in the solution, it is important to know how to differentiate the lapilli. We then use fine forceps to push the otoliths out of the drop of bleach into a drop of water; the otoliths are too small to actually pick up or grasp even with fine-tip forceps. We then push the otoliths from the water into a drop of ethanol, and then ultimately onto a dry section of the dissecting dish so that they can air dry. Mounting larval otoliths is generally similar to the larger otoliths with the exception of transfer to the slide. To transfer otoliths onto the slide, we use fine forceps tipped with a small amount of the heated mounting media. The otolith is immersed in the mounting media on the forceps, and once the mounting media has cooled and slightly firmed, the otolith with the mounting media can be transferred to the slide. The slide is then slightly heated to adhere the mounting media to the slide and also so that the position of the otolith can be manipulated if needed.

Otolith Preparation and Reading

The increment structures of age-0 splittail otoliths are relatively easy to interpret. The increments of wild fish exhibit excellent contrast without any grinding or polishing. If it were not for the many cracks that obfuscate viewing planes, the otoliths would require no further preparation prior to reading; we have yet to discover lapilli otoliths from our ethanol-preserved specimens without cracks. For otoliths that require some preparation, we have found that very light polishing with 0.3 µm lapping film works well. It is important that the lapping film be adhered to a completely flat surface to ensure even polishing. We have also had success grinding the otoliths with 1200 grit wet sandpaper followed by polishing on a microcloth with 0.3 µm alumina. This method produces a very nice clean surface, but is messier and less convenient than the quick and dry lapping film technique. There is definitely a learning curve when it comes to polishing otoliths. It is very easy to over-polish the otoliths of age-0 splittail, resulting in an unreadable structure. Although it is fairly common practice with larger otoliths, polishing to the core of the otolith is not always necessary with age-0 splittail otoliths. As mentioned, the degree of polishing is largely determined by the number of cracks in the otoliths; otolith clarity and polishing intensity are inversely related. In some instances simply polishing down any mounting media overburden is all that is necessary. In addition, even small amounts of polishing seem to sometimes reduce the contrast between the increments, presumably because the increments are then viewed through

less material. We have also flipped the mounted otoliths and polished both sides, but have found that there is little, if any, improvement in readability.

Validation of Daily Increments and Time of First Increment Formation Using Known-age Fish

Known-age study fish originated from adult splittail maintained by the US Bureau of Reclamation's (USBR) Tracy Fish Collection Facility. The adults from which the study fish were produced were collected at the facility in 1998 as juveniles. They were maintained at ambient Delta water temperature and a natural photoperiod while they were grown-out to adulthood. Adult female splittail were injected with Ovaprim in April 2003 and ovulated eggs were recovered 24 to 48 hours post injection. The eggs were mixed with sperm from three males in 1.5-gallon plastic containers and mixed with bentonite to reduce adhesiveness. Eggs were rinsed after 20 minutes, placed in Pond RidIch (1%) for 5 minutes, and then transferred to an upwelling egg incubator using filtered Delta water. Eggs were maintained at 19 °C with a natural photoperiod (lights on timers). The eggs hatched after 5 days of incubation on 30 April and were transferred to 24-inch diameter black plastic tanks at 20 °C with a natural photoperiod. Larvae were fed rotifers and *Artemia nauplii* starting at 5 and 8 days post-hatch, respectively. Yolk sacs were completely depleted by 6 days post-hatch.

We have examined a number of these known-age fish and have found that the number of otolith increments matches age, thereby validating both daily increment deposition and that first increment forms on the day of hatch. One such example for a 15-day-old fish is given in Figure 3. However, a common problem that we encountered with these otoliths was that increment contrast was extremely poor, which made microstructural analysis very difficult. In fact, in most circumstances, we found that daily increments were very difficult to distinguish while subdaily increments were quite prevalent. Very minor focus manipulations were all that was needed to display daily versus subdaily increments (Figure 3). It should be noted that we are not completely certain if the subdaily increments, such as those shown in Figure 3, are indeed subdaily increments or simply visual artifacts. Answering such a question would require highly sophisticated techniques, such as scanning electron microscopy, to view the surface of the otolith in three dimensions. Understanding the morphological differences between daily and subdaily increments and knowing the age of the study fish was critical to our ability to examine these particular otoliths. We believe this contrast problem stems from the fact that the fish were reared at constant temperatures. Several studies have shown that fish reared under a natural fluctuating temperature cycle have otoliths that exhibit better contrast than fish reared under constant temperature.

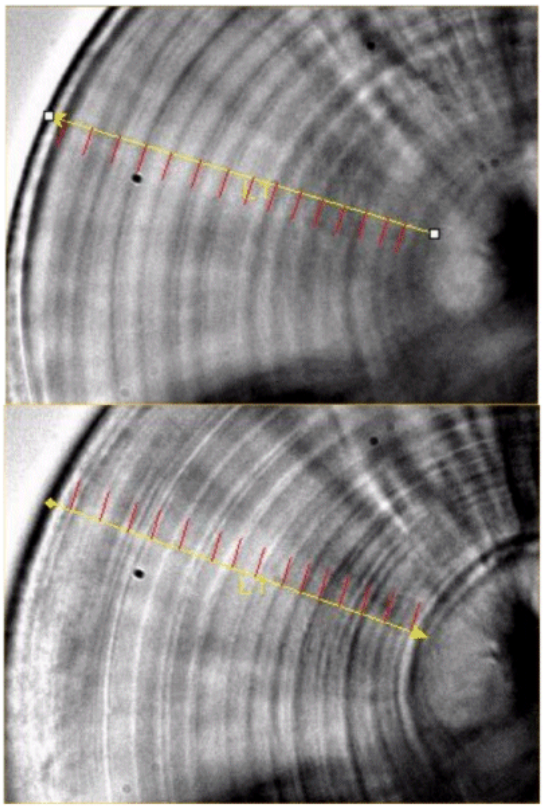

Figure 3 Photomicrographs of a lapillus otolith from a 15-day old splittail. Top panel shows daily increments. Bottom panel shows subdaily increments that appear between the daily increments when the focus is manipulated. Subdaily increments are most prominent near the core.

Conclusions

We conclude that otolith microstructure analysis is a viable method for age and growth studies of age-0 splittail. Using both marked wild fish and known-age fish, we have been able to validate daily growth increments and time of first increment formation. This information will enable us and other researchers to test hypotheses about mechanisms contributing to survival and recruitment of young splittail. Further study will determine the approximate maximum age at which daily aging becomes increasingly difficult or no longer possible.

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San Joaquin River Deep Water Ship Channel Water: Not San Joaquin River Watershed Water Below Columbia Cut

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Some authors of *IEP Newsletter* articles and others make reference to "San Joaquin River water" being in the San Joaquin River (SJR) Deep Water Ship Channel (DWSC) in the northern and eastern part of the Delta. However, the Dissolved Oxygen (DO) Total Maximum Daily Load (TMDL) studies that have been conducted over the past four years in the DWSC have found that, except possibly under SJR flood flow conditions, the water in the San Joaquin River DWSC downstream of Disappointment Slough/Columbia Cut is Sacramento River water, not San Joaquin River water. This situation is the result of the state and federal project pumps (Project) that export water from the South Delta, creating a strong Sacramento River water flow through the Central Delta to the South Delta that crosses the SJR DWSC at and downstream of Turner Cut/Columbia Cut. These waterbodies are located 7 and 10 miles, respectively, downstream of the Port of Stockton (Figure 1). The San Joaquin River water at these waterbodies is then mixed with the Sacramento River water on its way to the export pumps (at Clifton Court and, to some extent, at Tracy) via Middle River and Old River in the Central Delta.

Information on Mixing of Sacramento River Water in the SJR DWSC

Lee and Jones-Lee (2000, 2001, 2003a,b) reported--based on a review of data from the Department of Water Resources (DWR) Division of Operations and Maintenance "Hayes" SJR DWSC monitoring cruises (Hayes and Lee 1998, 1999, 2000; Ralston and Hayes 2002; Giovannini and Hayes 2003) that have been conducted during the summer and fall over the years—that the low-DO problem that frequently occurs during the summer and fall and sometimes in the winter does not occur in the SJR DWSC downstream of Disappointment Slough/Columbia Cut. This arises from the fact that the Sacramento River water that is drawn to the South Delta by the Projects' export pumps has a low oxygen demand/low algal content. This situation is also evident from the specific conductivity (EC) data. The SJR has a summer/fall EC typically greater than 500 µmhos/cm (µS/cm), while the Sacramento River water EC is typically less than 200 µmhos/cm. Brown (Jones & Stokes 2002) conducted a study upstream in the SJR DWSC on the mixing of Sacramento River water with the SJR DWSC near Turner Cut. He reported that, at times under low SJR DWSC flow, the SJR DWSC downstream of Turner Cut is dominated by tidally induced upstream migration of Sacramento River water.

An example of this type of situation occurred on July 17, 2003, when the author and his associates (Lee and Morgan, 2003), with DeltaKeeper boat and staff support, conducted a monitoring tour of the SJR DWSC, Turner Cut down to Clifton Court via Empire Cut, Middle River, Victoria Canal, and then north from Clifton Court to Columbia Cut via Old River (Figure 1). The specific conductivity (corrected to 25 °C) of the SJR DWSC water upstream of and near Turner Cut was about 400 µmhos/cm. Beginning at Turner Cut, under high tide conditions on July 17, 2003, the specific conductivity dropped to about 155 µmhos/cm, and remained in the range of about 150 to 270 µmhos/cm throughout this part of the tour. Headreach Cutoff, which connects the SJR DWSC to Columbia Cut, had an EC of 145 µmhos/cm. The decreased specific conductivity beginning at Turner Cut, through the Central Delta, was due to the low EC of the Sacramento River water mixing with the SJR DWSC water.

On September 11, 2003, the first of the 2003 summer-fall DWR Hayes cruises of the San Joaquin River DWSC was conducted. Giulian (2003) has made the preliminary data from this cruise available for review. In 2003 the DWR cruises have been expanded to include EC measurements. Examination of these data shows that the seven stations monitored in the SJR DWSC from Prisoners Point to just downstream of Turner Cut had specific conductance values typically less than 300 µmhos/cm. However, at the station just upstream of Turner Cut, the EC increased to 623 µmhos/cm, and remained from 600 to about 660 µmhos/cm for the seven stations in the DWSC monitored from Turner Cut to within the Port of Stockton. Coincidentally, the DO in the SJR DWSC in the surface and bottom waters upstream of Turner Cut was found to be less than the 6 mg/L water quality objective, which was established to protect Chinook salmon homing migration. Just downstream of Rough and Ready Island, the DO in the bottom waters at

the time of measurement was about 3 mg/L, with the surface waters having a DO of about 4.5 mg/L. At the DWR Rough and Ready Island continuous monitoring station, the early morning DO was about 3 mg/L. Similar EC results have been obtained in subsequent Hayes cruises, as well as a subsequent tour conducted by the author on September 17, 2003 (Lee and Morgan, 2003). It is clear from these data that the water in the SJR DWSC from the Port of Stockton to Turner Cut is derived from the SJR DWSC watershed, while the water in the SJR DWSC below Turner Cut to Prisoners Point is derived from the Sacramento River.

Jassby and others (2003) have recently summarized a number of their papers and reports on the lack of phytoplankton in the Delta as part of the Delta aquatic food web. One of the consequences of the diversion of the SJR DWSC water into the Central Delta via Turner Cut and Columbia Cut is to provide additional phytoplankton into the Central Delta, and thereby help support the Delta food web.

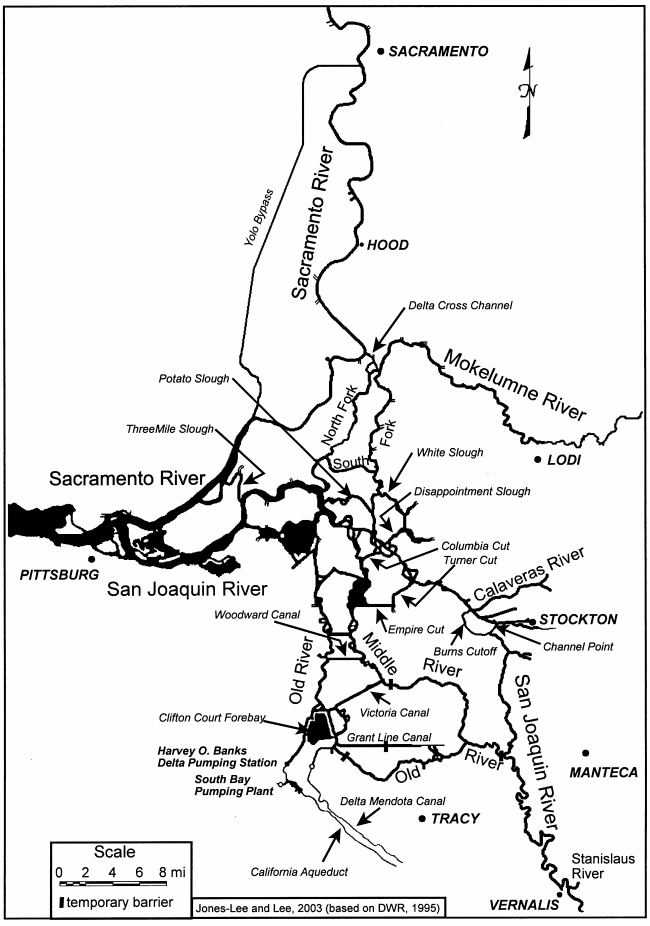

Figure 1 Simplified map of Delta Channels

Typical SJR DWSC/Sacramento River Water Flow through the Central Delta

The typical summer recent-year San Joaquin River at Vernalis flows have been on the order of 1,100 to about 2,500 cfs. The SJR Vernalis water splits at the intersection with Old River, where at times, when the Head of Old River barrier is not in place, much of the SJR Vernalis water is drawn into the South Delta via Old River, which, in turn, is pumped from the South Delta by the Tracy export pump. At times, during a wet year or when there are major SJR watershed reservoir releases, the flows of the SJR through the DWSC can be >1,500 cfs. During these times, much of the SJR Vernalis water is carried through the DWSC to Turner Cut and Columbia Cut. If it is assumed that the flow of the SJR at Vernalis is 1,500 cfs and half of it is drawn down Old River into the South Delta, then there is 750 cfs of SJR watershed water that mixes with the Sacramento River water at Turner Cut and Columbia Cut.

According to DWR Operations and Maintenance records, the State Project and the Federal Project pumps typically export on the order of 10,000 to 13,000 cfs from the South Delta, which means that since the total SJR Vernalis water that is either drawn into the South Delta or that passes through the SJR DWSC to Turner Cut and Columbia Cut into the Central Delta is on the order of 1,000 to 2,000 cfs, the Sacramento River watershed water that is drawn to the South Delta by the export pumps is about 10,000 to 12,000 cfs during the summer and fall. The amount of the Sacramento River water that is drawn to the Central Delta/South Delta is somewhat greater than the difference between the SJR Vernalis water flow and the export pumping, due to irrigation consumption of water in the Delta. Some of the Sacramento River water/SJR DWSC water that is transported through Turner Cut/Columbia Cut via Middle River that is drawn to the South Delta enters the South Delta channels through the temporary barriers on Middle River, Grant Line Canal and Old River during high tide. Since the state Project pumps at Tracy typically export about 4,600 cfs, and the maximum SJR Vernalis water that enters the South Delta is on the order of 1,000 to 2,000 cfs, over 2,000 cfs of Sacramento River water must be added to the South Delta to meet the needs for the State Project pumps and South Delta irrigation.

Impact of SJR DWSC Water into the Central Delta on Chinook Salmon Homing

The diversion of all of the San Joaquin River DWSC water at Turner Cut/Columbia Cut to the Central Delta has important implications for Sacramento River watershed fish

homing during much of the year. Fish entering the Delta from San Francisco Bay that originally develop in the San Joaquin River watershed rivers have little or no home stream chemical signal until they reach the SJR DWSC water at Columbia Cut and Turner Cut or in Middle River where it mixes with Empire Cut. Even then, the signal may be weak, because of upstream diversions of their home stream water. There would also be a weak signal of SJR watershed water in the South Delta, to the extent that there is home stream water in the South Delta that has been derived from the SJR at Vernalis before this water is drawn to the State Project pumps.

At the August 2003 CA Bay-Delta Authority Science Program workshop on Chinook salmon and steelhead restoration, several investigators (such as K. Williamson of UCD) reported that the Chinook salmon that are found in the SJR watershed tributaries do not have a population genetic structure that is associated with a particular river. This is not surprising, since the fall-run Chinook salmon do not have a chemical signal to return to their home stream waters because of the diversion of their home stream water upstream of the SJR and through the split of the SJR at Old River, as well as the complete diversion of the SJR DWSC water at Columbia Cut/Turner Cut.

To the extent that the export pumping is reduced or shut down, the cross-SJR DWSC flow of the Sacramento River water downstream of Turner Cut will be reduced or eliminated. Under those conditions, some Sacramento River DWSC water that is present upstream of Turner Cut could make it further down the SJR DWSC, past Turner Cut. It appears, however, that this situation would be rare. With the proposed increase in export pumping, an even greater amount of Sacramento River water will be drawn south to the export pumps.

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